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EFFECT OF ACID GASES ON THE PIGMENT COMPOSITION OF THE LEAVES OF TREES AND LAWN PLANTS

[Vliyaniye kislykh gazov na pigmentnyy sostav list'yev drevesnykh i gazonykh rasteniy]

by

V. V. Suslova and V. S. Nikoloyevskiy

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The chlorophyll (I) a and b, carotene (II), lutein (III), violaxanthin (IV), and neoxanthin (V) contents in the leaves of plants, subjected during various phases of their growth and development to acid gases such as SO_2, NO_2, F, HF, and P_2O_5 in various concns., were studied spectrophotometrically and by paper chromatog. Exposure to gases of lawn grasses with different gas resistance caused nonsignificant changes in their pigment contents. Woody plants revealed an inverse relation between the content of pigments and their gas resistance. The gas-resistant plants contained less pigments and lower Ia/Ib ratio. Differences in the relative distribution of pigments in all plants were nonsignificant. Lawn grasses decreased their pigments during phases of growth under the influence of acid gases. Pigment system compn. in lawn grasses was dependent on SO_2 concn., time of exposure, and species properties. Low concns. of SO_2 during the 1st day caused pigment decompn. and on the 2nd day a decrease of the pigment content.

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High concns. of SO_2 stabilized on the 1st and strongly decompd. on the 2nd day the plant pigments. Individual and total pigment in non-resistant and medium-gas-resistant woody plants decreased considerably and in the gas-resistant plants even increased with an increase of Ia/Ib ratio. Dependence between the gas resistance and individual and total pigments contents in the woody plants was obsd. The I and II stabilities in the plants in vitro were low. Statistical calcns. revealed a dependence of xanthophylls and III-IV contents on gas resistance.

The transient action of lethal and sublethal concentrations of sulfur dioxide under experimental conditions (Nikolayevskiy, Suslova, 1969) does not give a distinct picture of change in the pigment composition of leaves. The mechanism of increase in concentration of certain pigments on the second day after the action of the gas is not clear. In 1968, we continued study of the pigment composition of the leaves of two species of lawn grass by phase of growth and development (second year) and the effect of sulfur dioxide on them. The procedure of these experiments has been described previously (Nikolayevskiy, Suslova, 1969). In 1969, we attempted to conduct a comparative study of the pigment composition of the leaves of lawn (second year) and woody plants, growing in the botanical garden and at a chemical plant. The botanical garden of the university was provisionally used as the control, since, after conversion of the railroad transport to electric traction, air pollution by sulfur dioxide in this area (according to the data of the sanitary-epidemiological station) does not exceed permissible levels. At the chemical plant, the lawn and woody plants are periodically subjected, in the course of a year, to the action of a number of acid gases (SO_2, NO_2, F, HF, P_2O_5), in concentrations above permissible levels. Therefore,

the woody plants studied differed comparatively clearly in gas resistance. Earlier (Nikolayevskiy, Suslova, 1969), the effect of SO_2 on the pigments of common fescue (resistant species) and timothy (nonresistant species) was studied under experimental conditions; comparative study (control-test) of the pigments in these species was continued in 1968-1969.

In addition, the gas resistance of second year fescue was close to the resistance of timothy, both under experimental and factory conditions, as a consequence of acceleration of the life processes.

Experimental Method

The concentrations of pigments (chlorophyll a and b, carotene, lutein, violaxanthin, neoxanthin) in lawn grasses was determined in duplicate, by phases of growth and development, by paper chromatography (Bazhanova, Maslova, Popov, Popova, Sapozhnikov, Eydelman, 1964), in a SF-5 spectrophotometer. The chlorophyll a and be concentrations were calculated by the formulas:

$$Cl_a = 9.784 \cdot E662 - 0.99 \cdot E642$$

$$Cl_b = 21.426 \cdot E642 - 4.65 \cdot E662.$$

A tenfold determination of the damage to lawn grasses at the factory was made, simultaneously with sampling the materials.

The pigment concentrations in woody plants were determined in August 1969, when leaf damage was clearly expressed under factory conditions. Pigment concentrations were calculated by wet and dry weight, since we had previously (Nikolayevskiy, 1966) established an inverse correlation between damage and total irrigation of the leaves. Besides, the relative content of individual pigments in the total amount was calculated (in percent), and a correlative connection was revealed

between damage and pigment content by wet and dry weight (according to N. L. Leont'yev, 1962).

A study was carried out in 1968, of the effect of sulfur dioxide on the spectral properties of the pigments. For these purposes, plants damaged (test) and undamaged (control) by sulfur dioxide were used. The effect of 10% SO_2 was studied on rate of decomposition of individual pigments in solution. For this, 1 ml of 10% SO_2 was passed through it (in a cuvette) at 2 min intervals, and the concentration was measured in the SF-5, until complete destruction of the pigment (until bleaching of the solution or until reduction in concentration stopped).

Results of Experiments

The change in damage and pigment concentration in two species of lawn grasses, by phases of growth and development, are presented in Figs. 1 and 2.

As was noted above, the gas resistance of second year common fescue in the tubing, heading and flowering phases approximate those of timothy, as a consequence of acceleration of the life processes.

While, under experimental conditions, the gas resistance of both species of lawn grasses in the second and third years was almost identical, under factory conditions (Fig. 1b) fescue in the third year was damaged considerably less than timothy, in the heading, flowering and ripening phases.

In common fescue, compared to timothy, there is more chlorophyll a and b and total yellow pigments and more variation in all pigments by phases of growth and development (Table 1). The value of the ratio chlorophyll a/chlorophyll b is close in both species, but the value of the

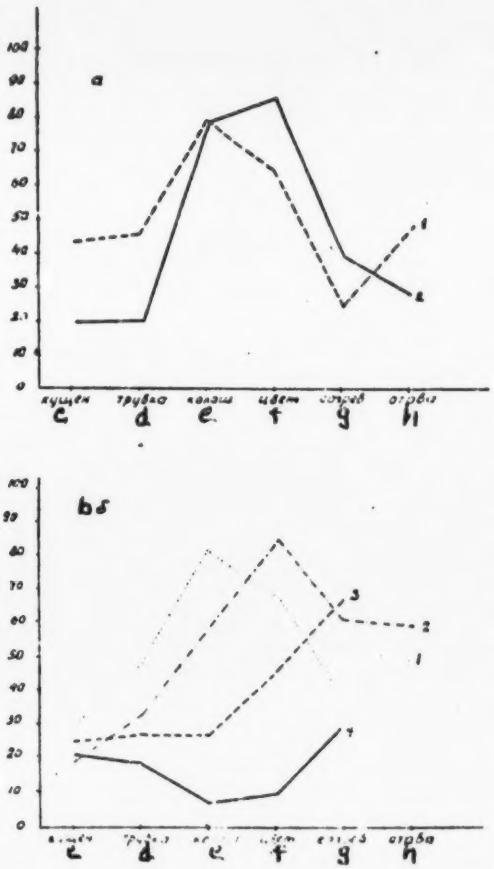


Fig. 1. Change in gas resistance of lawn grasses by phase of growth and development (leaf damage in % of total length on ordinate; phase of growth on abscissa): a, 2nd year, 1968; b. 3rd year, 1969; 1. timothy grass, botanical garden; 2. common fescue, botanical garden; 3, timothy grass, chemical plant; 4. common fescue, chemical plant

Key: c tillering
d tubing
e heading
f flowering
g ripening
h aftergrass

ratio chlorophyll a + b/yellow pigments is greater in fescue. Compared with the first year of growth (Nikolayevskiy, Suslova, 1969), the content of green pigments increased by 2-2.5 times in both species and, of yellow, 3-4 times. The increase in content of chlorophyll b and lutein is especially noticeable; therefore, the value of the chlorophyll a/chlorophyll b ratio decreased by 1.5-2 times, the value of the ratio of the total chlorophyll to yellow pigments was unchanged, and the value of the ratio of total xanthophylls to carotene increased.

In the third year (Fig. 2), the content of all pigments also was higher in fescue in all phases (with the exception of flowering), and a sharper decrease in their content is observed in the flowering phase.

In both species, the reduced form, chlorophyll a, predominates among the green pigments and the oxidized forms (violaxanthin, neoxanthin, lutein), among the yellow.

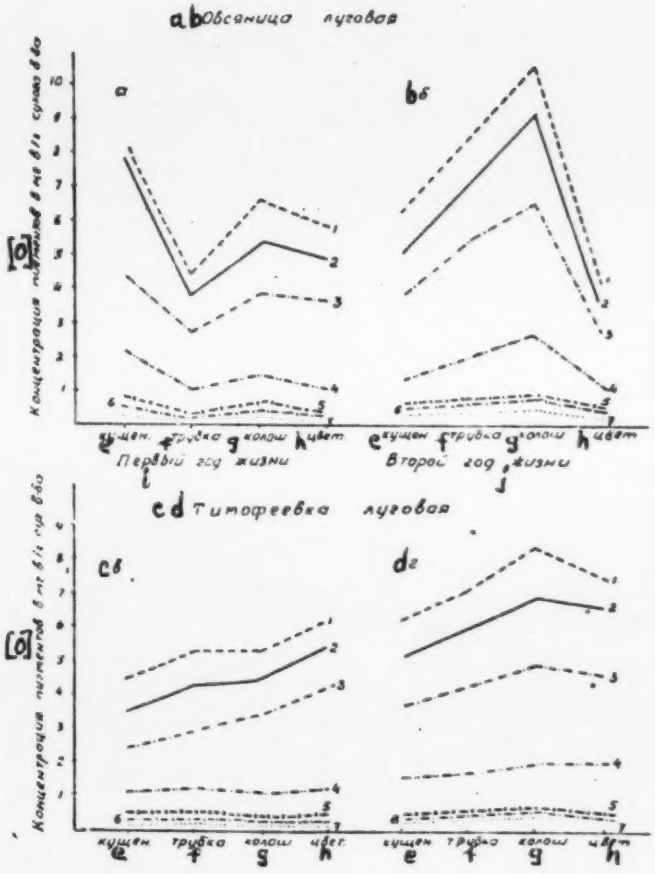


Fig. 2. Change in pigment content of 2nd and 3rd year lawn grasses, by phase of growth (pigment concentration, mg/g dry weight on ordinate [O]): a. common fescue (2nd year); b. common fescue (3rd year); c. timothy (2nd year); d. timothy (3rd year); 1. total of all pigments; 2. total chlorophylls a + b; 3. chlorophyll a; 4. chlorophyll b; 5. lutein; 6. violaxanthin; 7. neoxanthin

Key: e tillering
f tubing
g heading
h flowering
i 1st year
j 2nd year

TABLE 1

PIGMENT CONTENT BY GROWTH AND DEVELOPMENT PHASES OF 2nd YEAR LAWN GRASSES (1968, BOTANICAL GARDEN)

a Вид, фаза	b Хлорофилл a	c Хлорофилл б	d Хлорофилл a + б	e Каротин	f Ксантофиллы: h лютеин	i виолаксантин	j неоксантин	k сумма	l Сумма желтых пигмент.	g Отношения: m хл. a / хл. б	n хл. a+б / желт. пигм.	o ксантофил. / каротин
p Овсяница луговая												
q кущение	4,36	2,16	6,52	0,032	0,88	0,461	0,242	1,583	1,615	2,02	4,05	49,3
r трубка	2,8	1,1	3,90	0,026	0,292	0,101	0,141	0,317	0,563	2,57	6,9	20,0
s цветение	3,9	1,5	5,40	0,031	0,615	0,401	0,277	1,296	1,327	2,6	4,10	41,5
t отава	3,74	1,14	4,88	0,015	0,481	0,305	0,227	1,013	1,058	3,3	4,6	22,5
u Тимофеевка луговая												
q кущение	2,47	1,07	3,54	0,013	0,471	0,[illegible]6	0,141	0,883	0,926	2,3	3,8	20,5
r трубка	2,97	1,23	4,20	0,117	0,493	0,307	0,242	1,042	1,159	2,42	3,65	8,9
s цветение	3,37	1,11	4,48	0,064	0,391	0,202	0,150	0,745	0,807	3,03	5,5	11,6
t отава	4,18	1,22	5,40	0,018	0,445	0,208	0,174	0,827	0,845	3,4	6,4	47,0

Key:
a Species, Phase
b Chlorophyll a
c " b
d " a+b
e Carotene
f Xanthophylls
g Ratios
h Lutein
i Violaxanthin
j Neoxanthin
k Total
l " yellow pigments
m Chlorophyll a/Chlorophyll b
n " a+b/yellow pigments
o Xanthophyll/Carotene
p Common Fescue
q Tillering
r Tubing
s Flowering
t Aftergrass
u Timothy

[Translator's Note: Commas in tabulated figures are equivalent to decimal points.]

There are significant differences in the concentrations of the individual pigments of the species studied in the flowering phase. There is more chlorophyll a and b, lutein, violaxanthin, neoxanthin and total of all pigments in fescue than in timothy. In the tubing phase, the pigment content of fescue decreases, and it increases in timothy (especially chlorophyll a and carotene). In the succeeding phases, changes in concentration of the individual pigments are less significant, but frequently opposite.

The results of the effect of sulfur dioxide on the pigment composition of two-year plants by phases are presented in Table 2. The pigment concentrations in the control and test plants were determined 1 hour after fumigating with SO_2 and after 24 hours. For convenience in comparison, the test results are presented in percent.

As a result of the action of SO_2 (concentration $5 \cdot 10^{-5}$, 1 hour), with complete absence of damage to fescue or a slight decrease in turgor (aftergrass, flowering), timothy plants were severely damaged in the tillering, flowering and aftergrass phases. Slight damage to timothy was found in the tubing phase. While no connection of damage to pigment content can be traced in fescue, there is some inverse proportional relation of damage to carotene content in timothy. Increased damage to timothy in the aftergrass phase coincides with a low carotene content, and a decrease in damage in the tubing phase, with a high content of it. According to the data of N. Bishop (1962), carotene fulfills a protective function in the chloroplast, preventing chlorophyll a and b from bleaching in bright light. It is possible that, in the case of action of SO_2, carotene protects the chlorophylls from photodynamic oxidation by light.

TABLE 2

EFFECT OF VARIOUS SO_2 CONCENTRATIONS ON PIGMENT CONTENT OF LAWN GRASSES BY GROWTH AND DEVELOPMENT PHASE

a Вид и фаза	b Варианты опыта	c Повреждаемость растений в %	d Содержание пигментов в % к контролю					
			e хлорофилл *a*	f хлорофилл *б*	g каротин	h лютеин	i виолаксантин	j неоксантин
k Кущение								
l Овсяница луговая	$SO_2 - 5 \cdot 10^{-5}$ — 1 день m	0	121,0	116,0	100,0	100,5	54,0	370,0
	" — 2 день m	0	99,0	106,6	96,0	42,0	56,0	112
	$SO_2 - 2 \cdot 10^{-4}$ — 1 день m	0	85,0	730	95,0	101,0	96,0	102
	" — 2 день m	93,0	24,0	44,0	—	34,0	14,5	69,5
n Тимофеевка луговая	$SO_2 - 5 \cdot 10^{-5}$ — 1 день m	0	118,0	122,0	—	101,0	71,0	176
	" — 2 день m	47,7	126,0	136,0	63,0	187,0	70,0	90
	$SO_2 - 2 \cdot 10^{-4}$ — 1 день m	0	94,0	91,0	23,4	80,0	235,0	—
	" — 2 день m	69,2	56,0	63,5	—	34,0	53,0	47,0
o Трубка								
l Овсяница луговая	$SO_2 - 5 \cdot 10^{-5}$ — 1 день m	0	109,0	96,0	104,0	108,0	215,0	210
	" — 2 день m	0	170,0	212,0	0	232,0	162,0	172
n Тимофеевка луговая	$SO_2 - 10^{-4}$ — 1 день m	—	126,0	130,0	111,0	136,0	50,0	98,0
	" — 2 день m	6,6	106,0	99,0	174,0	116,0	75,0	106
p Цветение								
l Овсяница луговая	$SO_2 - 10^{-5}$ — 1 день m	0	118,0	102,0	81,0	118,0	55,0	89,0
	" — 2 день m	потеря тургора r	70,5	38,5	47,0	80,0	65,0	55,0
n Тимофеевка луговая	$SO_2 - 10^{-5}$ — 1 день m	—	89,0	103,0	75,0	206,0	129,0	202
	" — 2 день m	49,4	102,0	129,0	121,0	141,0	79,0	162
	$SO_2 - 10^{-4}$ — 1 день m	—	108,0	118,0	65,0	106,0	102,0	138
	" — 2 день m	72,9	95,0	91,0	—	73,0	30,0	87
q Отава								
l Овсяница луговая	$SO_2 - 10^{-4}$ — 1 день m	0	92,0	93,0	26,9	84,0	43,0	66,0
	" — 2 день m	потеря тургора r	40	74,0	119,0	58,0	32,0	57,0
	$SO_2 - 10^{-5}$ — 1 день m	0	116,0	130	150,0	110	120,0	187
	" — 2 день m	0	106,0	118	72,0	60	51,0	80
n Тимофеевка луговая	$SO_2 - 10^{-4}$ — 1 день m	0	82,0	118	0	92	58,0	100
	" — 2 день m	79,2	68,0	79,0	—	84	65,0	76
	$SO_2 - 10^{-5}$ — 1 день m	0	99,0	120	200	83	38,5	62,5
	" — 2 день m	46,5	78,0	103,0	67,0	100,0	74,0	73,0

Key:
a Species and Phase
b Test Version
c Plant Damage in %
d Pigment Content in % of Control
e Chlorophyll a
f Chlorophyll b
g Carotene
h Lutein
i Violaxanthin
j Neoxanthin
k Tillering
l Common Fescue
m day
n Timothy
o Tubing
p Flowering
q Aftergrass
r Loss of Turgor

Under the influence of sulfur dioxide ($5 \cdot 10^{-5}$, 1 hour) an increase in pigment content, especially carotene and neoxanthin, and a decrease in violaxanthin, takes place in fescue, in the tillering phase. Moreover, the values of the chlorophyll a/chlorophyll b and chlorophyll a + b/yellow pigment ratios are close to those of the controls. On the second day, the pigment content decreases (especially carotene, lutein, neoxanthin), a decrease in values of the xanthophyll/carotene ratio takes place and the chlorophyll a/chlorophyll b and chlorophyll a + b/yellow pigment ratios are similar to those of the controls. A high SO_2 concentration ($2 \cdot 10^{-4}$) or the first day causes a reduction in chlorophyll a and b concentration and negligible changes in the remaining pigments; on the second day, a sharp decrease in content of all pigments, especially violaxanthin, carotene and chlorophyll a, is observed in fescue. Moreover, the values of the chlorophyll a/chlorophyll b, chlorophyll a + b/yellow pigment and xanthophyll/carotene ratios decrease.

In timothy, in the tillering phase, the action of SO_2 ($5 \cdot 10^{-5}$) cause the same changes in pigment content on the first day as in fescue, but, on the second day, significant differences were found: concentrations of the pigments, chlorophyll a and b and lutein increased, and the value of the chlorophyll a + b/yellow pigment ratio increased. The SO_2 concentration ($2 \cdot 10^{-4}$) caused destruction of carotene and lutein and an increase in violaxanthin (by 135%) on the first day in timothy. On the second day, as in fescue, the content of all pigments decreased sharply.

In fescue, in the tubing phase, SO_2 ($5 \cdot 10^{-5}$) caused a strong increase in violaxanthin and neoxanthin content and a weak one in chlorophyll a and carotene. An increase in content of all pigments and complete

destruction of carotene was noted in it on the second day. In timothy, under the same conditions, an increase in chlorophyll a and b and lutein and decrease in violaxanthin was found on the first day and, on the second day, some decrease in chlorophyll b and violaxanthin and an increase in carotene content.

In fescue in the flowering phase, the yellow pigments are destroyed to a greater extent (SO_2, 10^{-5}, 1 hour), with the exception of lutein, and the chlorophyll content increases. On the second day, a decrease in concentration of all pigments occurs. In timothy in this phase, sulfur dioxide (10^{-5}) caused a decrease in chlorophyll a and carotene concentration and an increase in lutein and neoxanthin. On the second day, stabilization of pigment content and even some increase in them was observed.

A high SO_2 concentration (10^{-4}) caused an increase in pigment content, especially of neoxanthin, and a decrease in carotene content, in timothy on the first day. On the second day, a reduction occurred in the concentrations of all pigments, especially carotene.

In fescue, in the aftergrass phase, affected by SO_2 (10^{-5}), a decrease in content of all pigments, especially carotene and neoxanthin, was observed on the first day and, on the second day, a reduction in concentration of yellow pigments and an increase in content of chlorophyll b. A high concentration of SO_2 (10^{-4}) caused a reduction in carotene and violaxanthin concentration on the first day and, on the second, a reduction in all pigments, with the exception of carotene. In timothy in this phase, the SO_2 concentration (10^{-5}) caused a decrease in chlorophyll a and xanthophyll content and an increase in amount of chlorophyll b and

carotene. A reduction in concentration of all pigments, with the exception of lutein, and an increase in content of chlorophyll b was observed on the second day. The high concentration of SO_2 (10^{-4}) caused a decrease in content of all pigments, with the exception of chlorophyll b, on the first day and, on the second day, a still greater reduction in content of all pigments.

Thus, weak concentrations of SO_2 have nonuniform effects on common fescue pigments in different phases. While, in the tillering and after-grass phases, a large part of the pigments are preserved or their content is even increased, in the flowering phase, a number of pigments are destroyed (carotene, violaxanthin, neoxanthin). On the second day of the test, in all phases except tubing, considerable destruction of all pigments takes place. In distinction from fescue, weak concentrations of SO_2 on timothy cause an increase in content of the majority of pigments on the first day of the test. A similar picture was observed in first-year plants (Nikolayevskiy, Suslova, 1969).

SO_2 did not change the spectral properties of the pigments: the spectral curves of the control and test versions coincided.

The change in damage to lawn grasses, as a function of phase of growth and development and gas concentration, are presented in Table 2. It is clear from it that timothy is more severely damaged by the gas in the tillering phase than fescue. In one case, the SO_2 concentration ($2 \cdot 10^{-4}$) caused even greater damage to fescue. It is possible here that a nonuniform effect was manifested by separation of the plant from the root system before gasing and by the reaction of the stoma to the gas.

In 1969, the pigment concentrations in second-year lawn grasses in the botanical garden and at the chemical plant were studied (Figs. 3a, b, c, d). The pigment concentrations were calculated per g of wet and dry weight of leaves.

It is evident from Figs. 3 a and d that the content of almost all pigments of fescue grown in the garden was higher than that of timothy. The flowering and tillering phases were exceptions. Besides, during all phases of growth, fescue in the garden was damaged almost the same as timothy (Fig. 1). At the factory, timothy was damaged more severely in all phases of growth. In this manner, for a resistant species, a high content of the majority of the pigments is characteristic.

An increase in pigment content from the tillering phase to heading and reduction during blooming (garden) was observed in both species. At the factory, as a consequence of the constant action of acid gases and poisoned soils, an increase in pigment content in the leaves was observed only in the tillering and tubing phases, and a reduction in their concentrations then occurred. In calculation of the pigment concentrations by dry weight (Fig. 3b, d), no difference in content of them in the lawn grasses was observed. The results of the effects of acid gases on a plant under garden and factory conditions are shown in Table 3. It is evident from it that, during the course of a year, retention of all pigments in fescue was higher than in timothy. Consequently, acid gases cause less destruction of pigments in the former than in the latter. In some phases (flowering), this difference was 65%. Therefore, the resistance of individual pigments during all phases of growth turned out to be different. In the tillering period, the chlorophyll content of the leaves of both

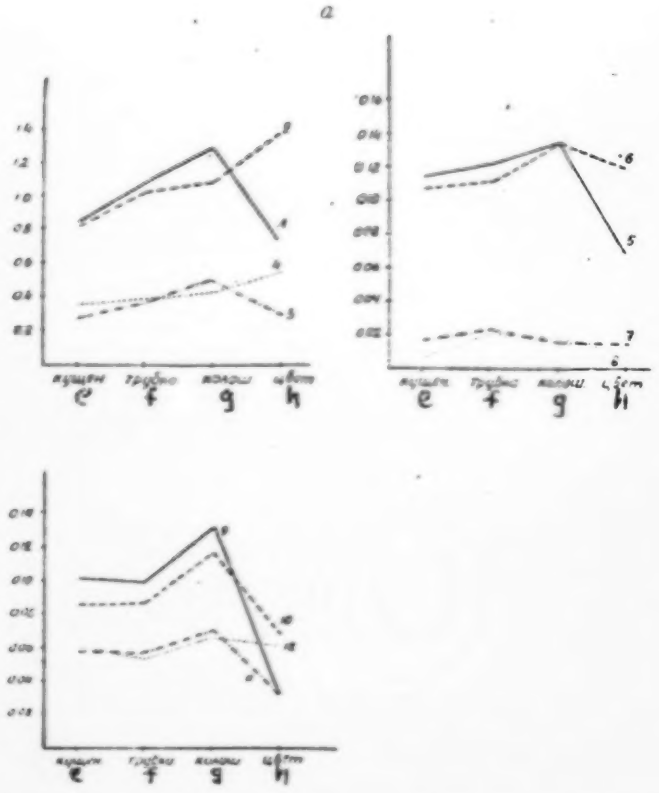
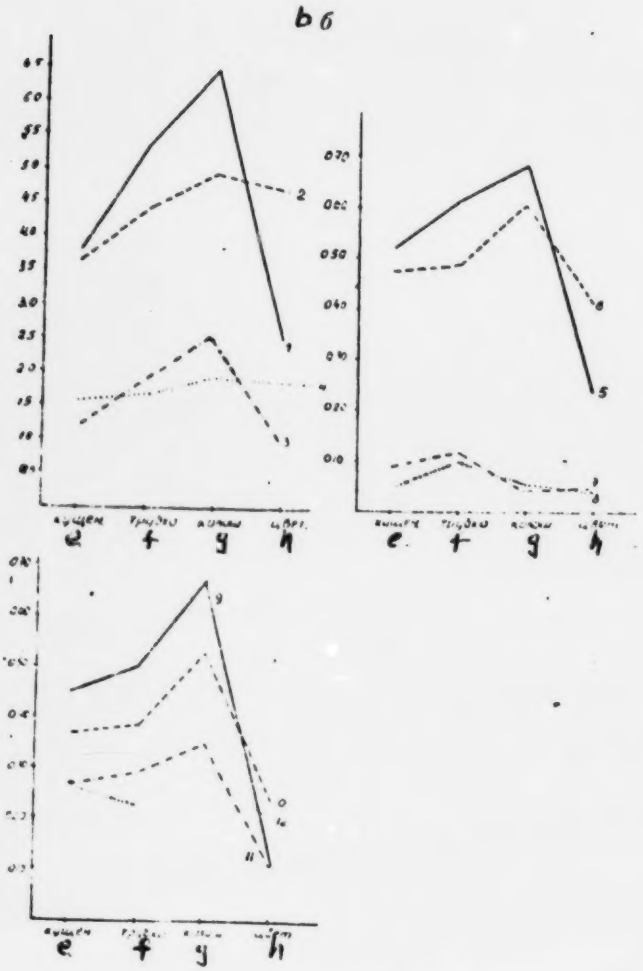


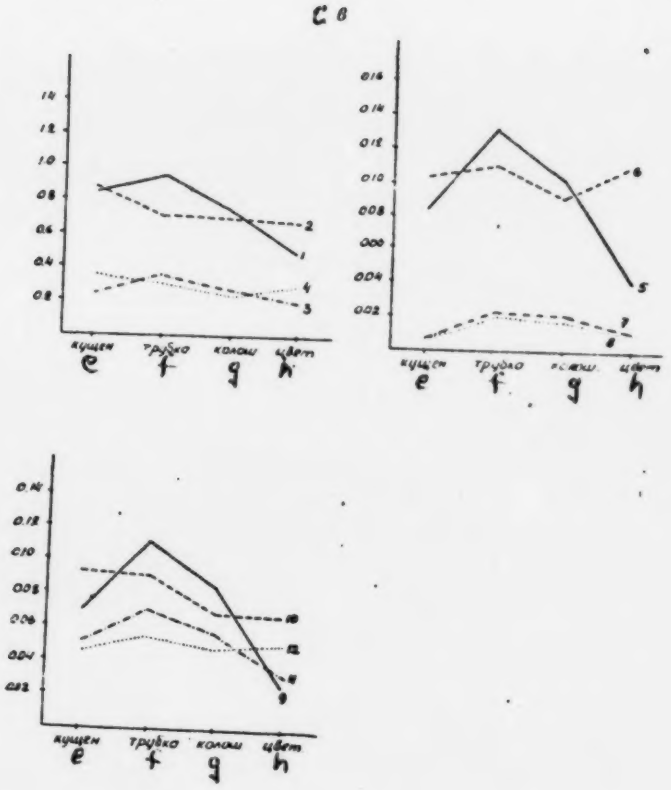
Fig. 3. Change in pigment concentration in lawn grasses in botanical garden and at factory: a. calculated on wet weight (garden); b. calculated on dry weight (garden); c. calculated on wet weight (factory); d. calculated on dry weight (factory); 1. chlorophyll a (fescue); 2. chlorophyll a (timothy); 3. chlorophyll b (fescue); 4. chlorophyll b (timothy); 5. lutein (fescue); 6. lutein (timothy); 7. carotene (fescue); 8. carotene (timothy); 9. violaxanthin (fescue); 10. violaxanthin (timothy); 11. neoxanthin (fescue); 12. neoxanthin (timothy).

Key: e tillering
f tubing
g heading
h flowering

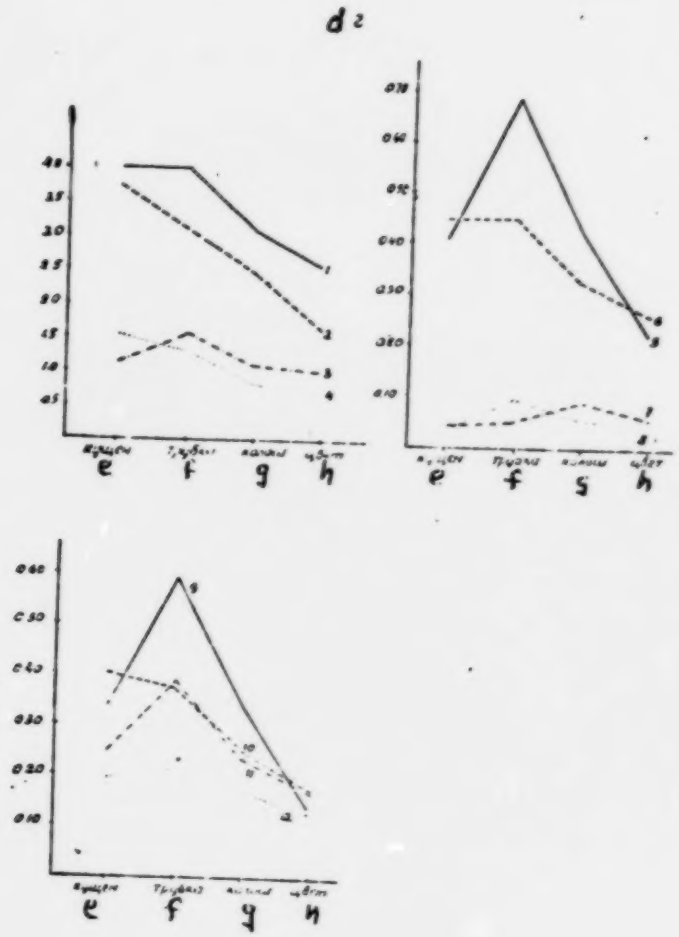
[Fig. 3b]



[Fig. 3c]



[Fig. 3d]



species remain close to that of the control, and the xanthophyll content decreased. On the average for the year, a somewhat greater reduction in chlorophyll content, compared with xanthophylls (by 8-12%) was observed under factory conditions. Thus, under factory conditions, compared with the garden, common fescue displays greater gas resistance than timothy in the third year.

TABLE 3

PIGMENT CONTENT OF LAWN GRASSES AT CHEMICAL PLANT, WITH RESPECT TO THE CONTROL (GARDEN) IN %

a Пигменты	b Содержание пигментов по фазам роста				c Среднее содержание за вегетационный период
	d кущение	e трубка	f колошение	g цветение	
h **Овсяница луговая**					
i Хлорофилл *а*	108	76	48	104	76
j Хлорофилл *б*	95	88	44	106	83
k Сумма хлорофиллов (*а* – *б*)	105	79	47	101	84
l Лютеин	80	112	62	93	87
m Виолаксантин	74	118	62	116	90
n Неоксантин	94	133	66	148	110
o Сумма ксантофиллов	80	118	59	112	92
p Сумма всех пигментов	100	86	51	104	74
q **Тимофеевка луговая**					
i Хлорофилл *а*	105	72	50	34	65
j Хлорофилл *б*	100	78	43	38	65
k Сумма хлорофиллов (*а* – *б*)	104	73	48	36	65
l Лютеин	97	94	53	66	77
m Виолаксантин	111	99	46	68	81
n Неоксантин	76	93	67	69	71
o Сумма ксантофиллов	96	96	61	64	77
p Сумма всех пигментов	102	72	49	39	65

Key:
a Pigments
b Pigment Content by Growth Phase
c Average Content in Growing Period
d Tillering
e Tubing
f Heading
g Flowering
h Common Fescue
i Chlorophyll a
j " b
k Total Chlorophyll (a+b)
l Lutein
m Violaxanthin
n Neoxanthin
o Total Xanthophylls
p Total of all Pigments
q Timothy

TABLE 4

RELATIVE CONTENT OF INDIVIDUAL PIGMENTS IN LAWN GRASSES BY PHASE OF GROWTH, CALCULATED ON WET WEIGHT

a Пигменты	b Содержание пигментов в % от суммы всех пигментов по фазам роста				
	c кущение		f трубка	g колошение	h цветение
	d 1-й год	e 2-й год			
i Тимофеевка луговая					
j Ботанический сад					
k Хлорофилл *а*	58,6	57,0	61,0	59,0	63,0
l Хлорофилл *б*	23,5	25,0	23,0	23,0	25,0
m Сумма хлорофиллов	82,1	82,0	84,0	82,0	88,0
n Каротин	1,4	0,5	1,3	1,0	0,5
o Лютеин	8,1	7,5	6,7	7,0	5,6
p Виолаксантин	6,0	5,8	5,0	6,4	3,2
q Неоксантин	2,4	4,2	3,0	3,6	2,8
r Сумма ксантофиллов	16,5	17,5	14,7	17,0	11,5
s Сумма каротиноидов	17,9	18,0	16,0	18,0	12,0
t Сумма всех пигментов	100,0	100,0	100,0	100,0	100,0
u Химический завод					
k Хлорофилл *а*	54,0	59,5	55,0	60,0	55,6
l Хлорофилл *б*	26,0	24,0	23,7	20,6	24,5
m Сумма хлорофиллов	80,0	83,5	78,7	80,6	80,1
n Каротин	2,5	0,5	1,7	1,4	1,0
o Лютеин	7,4	7,0	8,4	7,9	9,2
p Виолаксантин	5,0	6,0	7,0	5,9	5,5
q Неоксантин	5,0	3,0	4,2	4,2	4,2
r Сумма ксантофиллов	17,5	16,0	19,6	18,0	18,9
s Сумма каротиноидов	20,0	16,5	21,3	19,4	19,9
t Сумма всех пигментов	100,0	100,0	100,0	100,0	100,0
v Овсяница луговая					
j Ботанический сад					
k Хлорофилл *а*	53,3	60,0	62,0	60,6	62,6

Key:
a Pigment
b Pigment Content in % of Total of All Pigments by Phase of Growth
c Tillering
d 1st year
e 2nd year
f Tubing
g Heading
h Flowering
i Timothy
j Botanical Garden
k Chlorophyll a
l " b
m Total Chlorophylls
n Carotene
o Lutein
p Violaxanthin
q Neoxanthin
r Total Xanthophylls
s " Carotenoids
t " of all Pigments
u Chemical Plant
v Common Fescue

TABLE 4 (continued)

Хлорофилл *б*	27,3	19,0	20,7	23,4	24,6
Сумма хлорофиллов	80,6	79,2	82,7	84,0	87,2
Каротин	2,0	1,3	1,4	0,7	1,3
Лютеин	7,6	8,0	7,0	6,2	5,8
Виолаксантин	4,6	7,7	5,6	6,1	2,9
Неоксантин	5,2	4,0	3,3	3,0	2,8
Сумма ксантофиллов	17,4	19,7	15,9	15,3	11,5
Сумма каротиноидов	19,4	21,0	17,3	16,0	12,8
Сумма всех пигментов	100,0	100,0	100,0	100,0	100,0
Химический завод					
Хлорофилл *а*	56,3	65,2	58,4	58,8	61,7
Хлорофилл *б*	25,7	18,4	21,3	20,8	24,6
Сумма хлорофиллов	82,0	83,6	79,6	79,6	86,3
Каротин	0,4	0,5	1,4	1,7	1,3
Лютеин	8,3	6,6	8,0	7,9	5,3
Виолаксантин	5,3	5,4	6,7	6,5	3,2
Неоксантин	4,0	3,9	4,2	4,3	3,9
Сумма ксантофиллов	17,6	15,9	18,9	18,7	12,4
Сумма каротиноидов	18,0	16,4	20,3	20,4	13,7
Сумма всех пигментов	100,0	100,0	100,0	100,0	100,0

Calculation of the relative content of individual pigments in plants grown at the factory and in the garden (Table 4) showed that, during the year, even under the influence of acid gases, there is a stable ratio of individual pigments. Some differences in pigment content apparently occur within the limits of accuracy of the test.

In 1969, we conducted a comparative study of the pigment content (garden and factory) of 20 species of woody plants. The pigment contents were calculated on wet and dry weight (Tables 5-8). In addition, the relative content of individual pigments and the relation of plant damage to their concentrations were developed.

TABLE 5

PIGMENT COMPOSITION OF LEAVES OF TREE AND SHRUB SPECIES IN BOTANICAL GARDEN

a Группы растений по газоустойчивости и виды	b Повреждаемость в %	c Концентрация пигментов в мг/1 г сухого веса								d Отношения		
		e хлорофилл *a*	f хлорофилл *б*	g хлорофилл *a* – *б*	h лютеин	i виолаксантин	j неоксантин	k сумма желт. пигмент.	l сумма всех пигмент.	m хл. *a* / хл. *б*	n виолакс. / лютеин	o хл. *a* + *б* / желт. пигм.
p Устойчивые												
q Клен ясенелистный	26,6	2,58	1,31	3,89	0,55	0,19	0,19	0,93	1,92	1,96	0,31	4,1
r Вяз обыкновенный	8,2	3,01	1,36	1,37	0,45	0,17	0,05	0,67	5,01	2,20	0,38	6,5
s Снежноягодник	22,5	2,10	0,99	3,09	0,44	0,16	0,11	0,71	3,83	2,10	0,36	4,1
t Лох серебристый	5,0	1,96	1,59	3,55	0,59	0,19	0,19	0,97	4,72	1,20	0,32	3,6
u Бересклет европейский	11,9	3,30	1,07	4,37	0,48	0,21	0,20	0,82	5,19	3,10	0,63	5,3
v Жимолость татарская	8,2	1,91	0,80	2,71	0,39	0,33	0,21	0,[illegible]	3,67	2,40	0,85	2,9
x Среднее по группе	13,6	2,48	1,19	3,67	0,47	0,21	0,15	0,83	4,5	2,10	0,42	4,4
y Среднеустойчивые												
z Тополь бальзамический	29,0	2,02	1,56	3,58	0,40	0,21	0,16	0,87	4,45	1,3	0,42	4,1
a' Кизильник блестящий	34,3	1,96	0,97	2,93	0,40	0,21	0,27	0,88	3,81	2,0	0,53	3,3
b' Яблоня сибирская	49,6	1,81	0,76	2,57	0,32	0,17	0,14	0,63	3,20	2,4	0,54	4,1
c' Клен татарский	35,6	2,55	0,96	3,51	0,22	0,10	0,13	0,45	3,96	2,6	0,45	7,8

Key:
a Plant Group by Gas Resistance and Species
b Damage in %
c Pigment Concentration in mg/g of Dry Weight
d Ratio
e Chlorophyll a
f " b
g Chlorophylls a+b
h Lutein
i Violaxanthin
j Neoxanthin
k Total Yellow Pigments
l " of All "
m Chlorophyll a/ Chlorophyll b
n Violaxanthin/ Lutein
o Chlorophylls a+b/ Yellow Pigments
p Resistant (continued)
q Box Elder
r Common Elm

TABLE 5 (continued)

d' Черемуха обыкновенная	26,2	3,18	1,09	4,27	0,50	0,21	0,20	0,91	5,18	2,9	0,12	4,7
e' Калина обыкновенная	42,6	4,86	2,05	6,91	0,48	0,24	0,17	0,89	7,80	2,4	0,50	7,8
x Среднее по группе . . .	38,0	2,73	1,23	3,95	0,40	0,19	0,18	0,77	4,72	2,20	0,47	5,3
f' Неустойчивые												
g' Береза пушистая	51,8	2,66	1,21	3,87	0,53	0,33	0,22	1,08	4,95	2,2	0,62	3,5
h' Барбарис обыкновенный	59,3	1,01	0,34	1,35	0,31	0,23	0,26	0,80	2,15	2,9	0,74	1,7
i' Рябина обыкновенная	54,6	2,98	0,83	3,81	0,46	0,15	0,16	0,77	4,58	3,6	0,32	4,9
j' Акация желтая	79,0	6,51	2,10	8,61	0,74	0,18	0,27	1,19	9,80	3,1	0,24	7,2
k' Боярышник сибирский	48,6	1,89	0,74	2,63	0,31	0,24	0,17	0,72	3,35	2,5	0,77	3,6
l' Дерен белый	29,0	2,71	1,91	4,62	0,70	0,35	0,25	1,30	5,92	1,4	0,50	3,5
m' Ирга кожистая	61,1	0,73	0,40	1,13	0,18	0,07	0,08	0,33	1,46	1,8	0,39	3,4
n' Сосна обыкновенная	25,0	1,67	0,72	2,39	0,25	0,14	0,09	0,48	2,87	2,3	0,56	2,9
x Среднее по группе . . .	48,5	2,52	1,03	3,55	0,44	0,21	0,18	0,84	4,39	2,5	0,48	3,83

Key: (continued)

s Snowberry
t Silverberry
u Spindle-tree
v Tartar Honeysuckle
x Group average
y Moderately resistant
z Balsam Poplar
a' Hedge Cotoneaster
b' Siberian Crab-apple
c' Tartar Maple
d' Bird Cherry
e' Guelder Rose
f' Nonresistant
g' White Birch
h' Common Barberry
i' Mountain Ash
j' Siberian Pea-tree
k' " Hawthorn
l' Dogwood
m' Dwarf Shadbush
n' Scotch Pine

TABLE 6

PIGMENT COMPOSITION OF LEAVES OF TREE AND SHRUB SPECIES IN BOTANICAL GARDEN

a Виды и группы растений по газоустойчивости	b Повреждаемость в %	c Концентрация пигментов в мг/1 г сырого веса: хлорофилл *a* M ± m	хлорофилл *б* M ± m	хлорофилл *a* + *б*	лютеин M ± m	виолаксантин M ± m	неоксантин M ± m	сумма желт. пигмент.	сумма всех пигмент.	d Отношения: хл. *a* / хл. *б*	виолакс. / лютеин	хл. *a* · *б* / жёлт. п.	o Процентное содержание пигмента от суммы всех пигментов: хлорофилл *a*	хлорофилл *б*	хлорофилл *a* + *б*	лютеин	виолаксантин	неоксантин	сумма желт. пигмент.
p Устойчивые																			
q Клен ясенелистный	26,6	0,57 ± 0,021	0,29 ± 0,016	0,86	0,12 ± 0,019	0,04 ± 0,007	0,04 ± 0,007	0,19	1,05	1,9	0,36	4,5	54,4	27,6	82,0	10,4	3,8	3,8	18,0
r Вяз обыкновенный	8,2	1,18 ± 0,004	0,53 ± 0,029	1,71	0,18 ± 0,02	0,07 ± 0,008	0,02 ± 0,007	0,27	1,98	2,2	0,39	6,3	59,6	26,8	86,4	9,1	3,5	1,0	13,6
s Снежноягодник	22,5	0,71 ± 0,016	0,34 ± 0,049	1,05	0,15 ± 0,00	0,05 ± 0,002	0,04 ± 0,001	0,24	1,29	2,1	0,33	4,4	55,0	26,4	81,4	11,6	3,8	3,2	18,6
t Лох серебристый	5,0	0,45 ± 0,004	0,37 ± 0,00	0,82	0,13 ± 0,001	0,01 ± 0,003	0,04 ± 0,002	0,21	1,02	1,2	0,31	3,9	45,6	35,9	79,5	12,7	3,9	3,9	20,5
u Бересклет европейский	11,9	1,12 ± 0,09	0,36 ± 0,01	1,48	0,13 ± 0,00	0,08 ± 0,015	0,07 ± 0,004	0,28	1,76	3,1	0,62	5,3	63,6	20,4	84,0	7,4	4,5	4,0	15,9
v Жимолость татарская	8,2	0,85 ± 0,041	0,35 ± 0,041	1,20	0,17 ± 0,01	0,14 ± 0,002	0,09 ± 0,001	0,40	1,60	2,4	0,82	3,0	53,1	21,9	75,0	10,6	8,75	5,6	24,95
x Среднее по группе	13,6	0,81	0,37	1,18	0,145	0,07	0,05	0,265	1,445	2,2	0,48	4,57	56,0	25,6	81,6	10,0	4,9	3,5	18,4
y Среднеустойчивые																			
z Тополь бальзамический	29,0	0,73 ± 0,01	0,57 ± 0,05	1,30	0,18 ± 0,002	0,08 ± 0,01	0,06 ± 0,004	0,32	1,62	1,3	0,44	4,1	45,0	35,2	80,2	11,1	4,9	3,7	19,7
a' Кизильник блестящий	34,3	0,71 ± 0,041	0,35 ± 0,037	1,06	0,14 ± 0,004	0,07 ± 0,008	0,09 ± 0,003	0,30	1,36	2,0	0,50	3,5	52,2	25,7	77,9	10,3	5,1	6,6	20,0
b' Яблоня сибирская	49,6	0,70 ± 0,14	0,29 ± 0,041	0,90	0,12 ± 0,005	0,07 ± 0,017	0,05 ± 0,011	0,21	1,14	3,5	0,58	3,4	61,4	17,5	78,9	10,5	6,1	4,4	21,1
c' Клен татарский	35,6	1,72 ± 0,077	0,65 ± 0,01	2,37	0,15 ± 0,00	0,08 ± 0,01	0,10 ± 0,002	0,33	2,70	2,6	0,53	7,2	63,7	24,7	88,4	5,5	3,0	3,1	11,6
d' Черемуха обыкновенная	26,2	1,22 ± 0,016	0,42 ± 0,016	1,64	0,19 ± 0,01	0,08 ± 0,002	0,07 ± 0,008	0,34	1,98	2,9	0,42	4,8	61,6	21,2	82,8	9,6	4,1	3,5	17,2
e' Калина обыкновенная	42,6	1,60 ± 0,176	0,68 ± 0,02	2,28	0,16 ± 0,008	0,08 ± 0,005	0,06 ± 0,015	0,30	2,58	2,36	0,50	7,6	26,4	62,0	88,4	6,2	3,1	2,3	11,6
x Среднее по группе	36,0	1,11	0,46	1,59	0,16	0,07	0,07	0,305	1,89	2,40	0,44	5,30	51,0	33,3	84,3	8,5	3,6	3,6	15,7
f' Неустойчивые																			
g' Береза пушистая	51,8	0,90 ± 0,01	0,41 ± 0,029	1,31	0,18 ± 0,005	0,11 ± 0,0016	0,07 ± 0,001	0,36	1,67	2,2	0,61	3,6	53,8	24,5	78,3	10,8	6,6	4,2	21,6
h' Барбарис обыкновенный	59,3	0,28 ± 0,024	0,10 ± 0,044	0,38	0,09 ± 0,006	0,06 ± 0,004	0,07 ± 0,009	0,22	0,60	2,8	0,67	1,7	46,6	16,6	63,2	15,1	10,1	11,6	36,8

(continued)

TABLE 6 (continued)

a Виды и группы растений по газоустойчивости	b Повреждаемость в %	c Концентрация пигментов в мг 1 г сырого веса: e хлорофилл а M ± m	f хлорофилл б M ± m	g хлорофилл а + б / а	h лютеин M ± m	i виолаксантин M ± m	j неоксантин M ± m	k сумма желт. пигмент.	l сумма всех пигмент.	d Отношения: m хл. а / хл. б	n виолакс. / лютеин	o хл. а + б / желт. п.	o' Процентное содержание пигмента от суммы всех пигментов: e хлорофилл а	f хлорофилл б	g хлорофилл а + б	h лютеин	i виолаксантин	j неоксантин	k сумма желт. пигмент.
i Рябина обыкновенная	54,6	1,22 ± 0,087	0,34 ± 0,016	1,56	0,19 ± 0,005	0,06 ± 0,032	0,06 ± 0,002	0,51	1,87	3,5	0,32	5,0	65,2	18,2	83,4	10,2	3,2	3,2	16,6
j Акация желтая	59,0	1,89 ± 0,045	0,47 ± 0,00	2,50	0,21 ± 0,0007	0,05 ± 0,004	0,08 ± 0,0016	0,34	2,84	3,0	0,24	7,3	66,5	21,5	88,0	7,3	1,7	2,8	11,9
k Боярышник сибирский	48,6	0,70 ± 0,06	0,26 ± 0,01	0,96	0,11 ± 0,01	0,08 ± 0,004	0,07 ± 0,004	0,26	1,22	2,7	0,73	3,7	57,4	21,3	78,7	9,1	6,5	5,7	21,3
l Дерен белый	29,0	0,81 ± 0,00	0,57 ± 0,013	1,38	0,21 ± 0,01	0,10 ± 0,004	0,07 ± 0,002	0,38	1,76	1,4	0,48	3,6	46,0	32,4	78,4	11,9	5,7	3,9	21,5
m Ирга колосистая	61,1	0,63 ± 0,00	0,35 ± 0,01	0,98	0,15 ± 0,00	0,06 ± 0,00	0,07 ± 0,005	0,28	1,26	1,8	0,40	3,5	50,0	27,7	77,7	11,9	4,8	5,5	21,2
n Сосна обыкновенная	25,0	0,78 ± 0,049	0,33 ± 0,037	1,11	0,12 ± 0,001	0,07 ± 0,001	0,04 ± 0,0016	0,23	1,34	2,4	0,58	4,8	58,2	24,6	82,8	8,9	5,2	3,0	17,1
X Среднее по группе	48,5	0,98	0,19	1,47	0,16	0,075	0,066	0,300	1,771	2,5	0,47	4,2	55,0	23,3	82,6	9,2	4,3	3,9	21,0

Key: o' % Pigment Content of Total of All Pigments

[Remainder of key same as in Table 5]

TABLE 7

PIGMENT COMPOSITION OF LEAVES OF TREE AND SHRUB SPECIES AT CHEMICAL PLANT

a Группы растений по газоустойчивости и виды	b Повреждаемость в %	c Концентрация пигментов в *мг* 1 *г* сухого веса								d Отношения		
		e хлорофилл *а*	f хлорофилл *б*	g хлорофилл *а+б*	h лютеин	i виолаксантин	j неоксантин	k сумма желт. пигмент.	l сумма всех пигмент.	m хл. *а* / хл. *б*	n виолакс. / лютеин	o хл. *а+б* / желт. пигм.
p Устойчивые												
q Клен ясенелистный	9,0	1,89	1,22	3,11	0,39	0,15	0,30	0,84	3,95	1,5	0,38	3,7
r Вяз обыкновенный	4,0	1,85	0,85	2,70	0,22	0,16	0,10	0,48	3,18	2,1	0,73	5,6
s Снежноягодник	1,0	2,43	0,86	3,29	0,28	0,10	0,07	0,45	3,74	2,8	0,35	7,3
t Лох серебристый	0,0	3,41	0,98	4,39	0,49	0,25	0,20	0,94	5,33	3,5	0,51	4,7
u Бересклет европейский	1,0	1,28	0,51	1,79	0,33	0,07	0,13	0,53	2,32	2,5	0,21	3,4
v Жимолость татарская	4,0	4,02	1,14	5,16	0,48	0,40	0,14	1,02	6,18	3,5	0,83	5,1
x Среднее по группе	3,0	2,63	0,93	3,56	0,36	0,19	0,16	0,71	4,27	2,6	0,53	6,0
y Среднеустойчивые												
z Тополь бальзамический	33,0	0,48	0,39	0,87	0,17	0,12	0,13	0,42	1,19	1,2	0,71	2,1
a' Кизильник блестящий	2,0	1,99	0,64	2,63	0,25	0,13	0,13	0,51	3,14	3,1	0,52	5,1
b' Яблоня сибирская	9,0	1,49	0,44	0,93	0,17	0,06	0,03	0,26	1,19	1,1	0,35	3,5
c' Клен татарский	15,0	1,17	0,33	1,50	0,19	0,09	0,05	0,33	1,83	3,5	0,47	4,5
d' Черемуха обыкновенная	42,0	0,85	0,67	1,52	0,18	0,10	0,08	0,36	1,88	1,3	0,55	4,2
e' Калина обыкновенная	7,0	0,75	0,32	1,07	0,04	0,05	0,10	0,19	1,26	2,3	1,25	5,6
x Среднее по группе	18,0	0,95	0,47	1,42	0,16	0,09	0,08	0,33	1,75	2,1	0,56	4,2
f' Неустойчивые												
g' Береза пушистая	65,0	1,67	0,44	2,11	0,25	0,16	0,09	0,50	2,61	3,8	0,64	4,2
h' Барбарис обыкновенный	30,0	0,96	0,36	1,32	0,19	0,13	0,07	0,39	1,71	2,7	0,69	3,4
i' Рябина обыкновенная	18,0	1,21	0,64	1,85	0,17	0,10	0,05	0,32	2,17	1,9	0,59	5,8
j' Акация желтая	60,0	2,36	0,93	3,29	0,24	0,18	0,08	0,50	3,79	2,5	0,75	6,6
k' Боярышник сибирский	10,0	0,79	0,74	1,53	0,19	0,10	0,09	0,38	1,91	1,1	0,53	4,0
l' Дерен белый	13,0	2,45	1,14	3,59	0,14	0,17	0,12	0,70	4,29	2,1	1,21	5,1
m' Ирга колосистая	15,5	0,92	0,48	1,40	0,21	0,12	0,16	0,49	1,89	1,9	0,57	2,8
n' Сосна обыкновенная	25,0	0,50	0,42	0,92	0,20	0,10	0,10	0,40	1,32	1,2	0,50	2,3
x Среднее по группе	29,5	1,34	0,64	1,98	0,20	0,13	0,095	0,42	2,40	2,15	0,65	4,25

[Key same as in Table 5]

TABLE 8

PIGMENT COMPOSITION OF LEAVES OF TREE AND SHRUB SPECIES AT CHEMICAL PLANT

a Газ	b Повреждаемость в %	c Концентрация пигментов в *мг*/1 *г* сырого веса								d Отношения			d' Процентное содержание пигментов от суммы всех пигментов						
		e хлорофилл *а* M ± m	f хлорофилл *б* M ± m	g хлорофилл *а* + *б*	h лютеин M ± m	i виолаксантин M ± m	j неоксантин M ± m	k сумма желт. пигментов	l сумма всех пигментов	m хл. *а* / хл. *б*	n виолаксантин / лютеин	o хл. *а* + *б* / желт. пигм.	e хлорофилл *а*	f хлорофилл *б*	g хлорофилл *а* + *б*	h лютеин	i виолаксантин	j неоксантин	k сумма желт. пигментов
p Ps																			
q Клен	9,0	0,51 ± 0,01	0,33 ± 0,01	0,84	0,11 ± 0,007	0,07 ± 0	0,07 ± 0	0,25	1,09	1,5	0,63	3,3	46,8	30,2	77,0	10,1	6,4	6,4	22,9
r Вяз с	4,0	0,64 ± 0,00	0,29 ± 0,02	1,93	0,07 ± 0,05	0,05 ± 0,011	0,03 ± 0,0016	0,15	1,08	2,2	0,71	6,2	59,3	26,8	86,1	6,5	4,5	2,7	13,9
s Снеж	1,0	0,85 ± 0,004	0,30 ± 0,002	1,15	0,09 ± 0,005	0,03 ± 0,003	0,02 ± 0,001	0,14	1,29	2,8	0,33	8,2	65,9	23,2	89,2	6,9	2,3	1,5	10,7
t Лох	0,0	0,93 ± 0,12	0,27 ± 0,05	1,20	0,13 ± 0,002	0,06 ± 0,01	0,05 ± 0,006	0,24	1,44	3,4	0,46	5,0	64,6	18,7	83,3	9,0	4,2	3,5	16,7
u Бере	1,0	0,40 ± 0,073	0,16 ± 0,021	0,56	0,11 ± 0,006	0,02 ± 0,00	0,04 ± 0,007	0,17	0,73	2,5	0,18	3,3	54,8	21,9	76,7	15,1	2,7	5,5	23,3
v Жим	4,0	1,25 ± 0,024	0,35 ± 0,01	1,60	0,15 ± 0,00	0,12 ± 0,004	0,04 ± 0,006	0,31	1,91	3,6	0,80	5,2	65,6	18,3	83,7	7,8	6,3	2,1	16,3
x Сред	3,0	0,765	0,280	1,015	0,11	0,06	0,04	0,21	1,255	2,7	0,54	5,0	62,5	23,18	84,0	8,0	4,8	3,2	16,0
y С р.																			
z Топо	33,0	0,17 ± 0,00	0,13 ± 0,01	0,30	0,06 ± 0,003	0,04 ± 0,002	0,04 ± 0,002	0,14	0,44	1,3	0,67	2,1	38,6	29,5	68,1	13,6	9,1	9,1	31,8
a' Кизи	2,0	0,81 ± 0,016	1,26 ± 0,01	1,07	0,10 ± 0,00	0,05 ± 0,007	0,05 ± 0,00	0,20	1,27	3,1	0,50	5,3	63,8	20,5	84,3	7,9	3,9	3,9	15,7
b' Ябло	9,0	0,21 ± 0,01	0,19 ± 0,013	0,40	0,07 ± 0,01	0,02 ± 0,004	0,01 ± 0,016	0,10	0,50	1,1	0,29	4,0	42,0	38,0	80,0	14,0	4,0	2,0	20,0
c' Клен	15,0	0,54 ± 0,016	0,15 ± 0,005	0,69	0,09 ± 0,001	0,04 ± 0,005	0,02 ± 0,006	0,15	0,84	3,6	0,45	4,6	64,3	17,8	82,1	10,7	4,8	2,4	17,9
d' Чере	42,0	0,29 ± 0,005	0,23 ± 0,01	0,52	0,06 ± 0,002	0,03 ± 0,004	0,02 ± 0,004	0,11	0,63	1,3	0,50	4,7	46,0	36,5	82,5	9,5	4,7	3,2	17,4
e' Кали	7,0	0,24 ± 0,1	0,10 ± 0,041	0,34	0,01 ± 0,007	0,017 ± 0,002	0,03 ± 0,003	0,05	0,39	2,4	1,00	6,8	61,5	25,6	87,2	2,6	2,6	7,4	12,6
x Сред	18,0	0,376	0,176	0,552	0,06	0,03	0,03	0,12	0,672	2,1	0,50	4,6	56,0	26,1	82,1	8,9	4,5	4,5	17,9
f' Не																			
g' Бере	65,0	0,62 ± 0,008	0,16 ± 0,065	0,78	0,09 ± 0,007	0,06 ± 0,012	0,03 ± 0,005	0,18	0,96	3,9	0,67	4,3	64,9	16,6	81,2	9,4	6,3	3,1	18,8
h' Барб	30,0	0,34 ± 0,07	0,13 ± 0,065	0,47	0,07 ± 0,0016	0,04 ± 0,011	0,03 ± 0,0016	0,14	0,61	2,6	0,57	3,3	55,7	21,3	77,0	11,5	6,5	4,9	22,9
i' Ряби	18,0	0,48 ± 0,06	0,25 ± 0,01	0,73	0,06 ± 0,032	0,04 ± 0,005	0,02 ± 0,0016	0,12	0,85	1,9	0,67	6,1	56,5	29,3	85,8	7,1	4,7	2,3	14,1
j' Акац	60,0	1,01 ± 0,075	0,40 ± 0,016	1,41	0,10 ± 0,01	0,08 ± 0,00	0,03 ± 0,005	0,21	1,62	2,5	0,80	6,7	62,3	24,7	87,0	6,2	4,9	1,8	12,9
k' Боярк	10,0	0,31 ± 0,049	0,28 ± 0,049	0,59	0,07 ± 0,002	0,04 ± 0,018	0,03 ± 0,009	0,14	0,73	1,1	0,57	4,2	42,4	38,3	80,7	9,6	5,5	4,1	19,2
l' Дере	13,0	0,88 ± 0,041	0,41 ± 0,016	1,29	0,14 ± 0,008	0,06 ± 0,006	0,04 ± 0,004	0,24	1,53	2,1	0,43	5,4	57,5	26,8	84,3	9,2	3,	2,6	15,7
m' Ирга	15,5	0,39 ± 0,01	0,20 ± 0	0,59	0,09 ± 0,005	0,05 ± 0,002	0,07 ± 0,005	0,21	0,80	1,9	0,55	2,8	48,8	25,0	73,8	11,2	6,2	8,8	26,2
n' Сосн	25,0	0,22 ± 0,01	0,18 ± 0,005	0,40	0,09 ± 0,001	0,04 ± 0,006	0,04 ± 0,003	0,17	0,57	1,2	0,45	2,3	38,6	31,6	70,2	15,8	7,0	7,0	29,8
x' Сред	29,5	0,53	0,25	0,78	0,09	0,05	0,036	0,176	0,956	2,1	0,56	4,4	55,5	26,2	81,7	9,4	5,2	3,7	18,3

[Key same as in Table 6]

It is evident from Table 5 that there are no significant differences in the pigment content (dry weight) of trees growing in the botanical garden. Only the values of the chlorophyll a/b, as well as violaxanthin/lutein ratios are somewhat lower in resistant species than in the non-resistant ones. There are no significant differences in the relative distributions of individual pigments, with the exception of chlorophyll b in moderately resistant species. In distinction from lawn grasses (Table 4), the chlorophyll a content is somewhat less and there are somewhat more yellow pigments in tree species.

In calculation of the pigment concentration on wet weight, it is evident (Table 6) that there are definite differences in the plants, which may be connected with their gas resistance. Thus, in resistant species, there is less chlorophyll a and b, lutein, neoxanthin and total pigments, than in the moderately resistant and nonresistant ones. The chlorophyll a/b ratio is less in resistant species and the total chlorophyll/yellow pigment ratio, in nonresistant species. Moreover, the relative distribution of individual pigments remain close to that calculated on dry weight. Variation in content of almost all pigments and their relative content is more significant in nonresistant species.

The acid factory gases and the more severe microclimate conditions at the chemical plant must undoubtedly affect the pigment content in the leaves of woody plants. While no significant differences in pigment content in woody plants (calculated on dry weight) were found in the botanical garden, at the factory (Table 7), the concentrations of all pigments were higher in resistant species than in the nonresistant and moderately resistant ones. The latter undoubtedly should be connected with

TABLE 9

PERCENTAGE PIGMENT CONTENT IN LEAVES OF WOODY PLANTS IN TEST (CHEMICAL PLANT), WITH RESPECT TO CONTROL (GARDEN)

a Группы растений по газоустойчивости и их виды	Повреждаемость в %		Сумма всех пигмент.	p' Сырой вес							q' Сухой вес						
	ботанический сад r'	химический завод s'	l	хлорофилл a e	хлорофилл б f	хлорофилл a+б g	лютеин h	виолаксантин i	неоксантин j	сумма желт. пигмент. k	хлорофилл a e	хлорофилл б f	хлорофилл a+б g	лютеин h	виолаксантин i	неоксантин j	сумма желт. пигмент. k
p Устойчивые																	
Клен ясенелистный	26,6	9,0	104,0	89,5	113,7	97,7	100,0	175,0	175,0	131,5	73,25	93,12	79,9	70,9	78,9	157,89	90,2
Вяз обыкновенный	8,2	4,0	54,5	54,2	54,7	54,4	38,9	71,4	150,0	55,5	61,46	62,5	61,79	48,8	94,1	200,0	71,64
Снежноягодник	22,5	1,0	100,0	119,7	88,2	109,5	60,0	60,0	50,0	58,3	115,7	86,8	106,5	63,6	62,5	50,0	60,8
Лох серебристый	5,0	0,0	141,4	206,6	72,97	148,1	100,0	150,0	125,0	114,3	173,97	61,6	123,7	83,05	131,5	105,2	96,66
Бересклет европейский	11,9	1,0	41,5	35,7	44,4	37,8	84,6	25,0	57,1	60,7	38,8	47,7	40,96	86,84	29,2	65,0	64,6
Жимолость татарская	8,2	4,0	119,0	147,0	100,0	133,3	68,2	85,7	44,4	77,5	207,2	142,5	188,3	123,1	121,2	66,7	109,6
Среднее по группе	13,6	3,0	93,2	109,0	78,7	97,0	78,6	94,6	100,2	82,5	112,0	82,0	100,2	79,4	86,2	107,46	82,2
v Среднеустойчивые																	
Тополь бальзамический	29,0	33,0	27,3	23,3	22,8	23,1	33,3	50,0	66,7	43,7	23,8	25,0	24,3	34,0	57,14	81,25	48,3
Кизильник блестящий	34,3	2,0	83,3	114,1	74,3	100,9	71,4	71,4	55,5	66,7	101,5	65,97	89,8	62,5	61,9	48,14	57,9
Яблоня сибирская	49,6	9,0	44,0	30,0	95,0	44,4	58,3	28,8	20,0	41,7	27,1	58,89	36,18	53,1	35,3	21,4	41,3
Клен татарский	37,6	15,0	31,0	31,4	23,1	29,1	60,0	50,0	20,8	45,4	45,9	34,4	42,7	86,4	90,0	38,5	72,3
[illegible] обыкновенная	26,2	42,0	31,8	23,8	54,8	31,7	31,6	37,8	28,8	32,3	26,7	61,5	35,6	36,0	47,6	40,0	39,6
Калина обыкновенная	12,6	7,0	15,1	35,3	6,2	14,9	6,2	12,5	50,0	16,7	36,6	6,6	15,5	8,3	20,8	58,8	21,3
Среднее по группе	30,0	18,0	38,5	42,7	46,0	40,5	43,5	41,8	40,0	41,0	41,9	42,0	40,7	46,7	52,1	48,0	46,9
f Неустойчивые																	
Береза пушистая	51,8	65,0	57,5	68,9	39,0	59,5	50,0	54,5	42,8	50,0	62,8	36,4	54,5	47,2	48,5	40,9	46,3
Барбарис обыкновенный	59,3	30,0	101,3	121,4	130,0	123,6	77,8	66,7	42,8	63,6	95,01	105,9	97,8	61,3	56,5	26,9	48,7
Рябина обыкновенная	54,6	18,9	45,5	39,3	73,5	46,8	31,6	66,7	33,3	38,7	40,6	77,1	48,5	36,9	66,7	31,2	41,5
Акация желтая	59,0	60,0	88,0	53,4	65,6	56,4	47,6	160,0	37,5	61,7	36,2	44,3	38,3	32,4	100,0	29,6	42,01
Боярышник сибирский	48,6	10,0	60,0	44,3	107,6	61,4	63,6	50,0	42,8	53,8	41,8	100,0	58,2	61,3	41,7	52,9	52,8
Дерен белый	29,0	13,0	86,7	108,2	71,9	93,4	66,7	60,0	57,1	63,1	90,4	59,7	77,7	58,6	48,6	48,0	53,8
Ирга колосистая	61,1	15,5	63,6	61,9	57,1	60,2	60,0	83,3	100,0	75,0	126,0	120,0	123,9	116,6	171,6	200,0	148,5
Сосна обыкновенная	25,0	25,0	42,5	28,2	54,5	36,0	75,0	57,1	100,0	73,9	29,9	58,3	77,3	80,0	71,4	111,0	83,3
Среднее по группе	48,5	29,5	68,3	65,3	74,5	67,2	59,0	87,0	57,0	60,0	65,0	75,0	72,0	61,7	76,9	70,1	64,6

Key: p' wet weight q' dry weight r' botanical garden s' chemical plant

[Remainder of key same as in Table 6]

the effect of the acid gases. In the leaves of resistant species (at the factory, compared with the garden), there is more chlorophyll a and yellow pigments (Table 9), and the concentrations of all pigments under factory conditions are lower than in the garden, in all remaining plants. Moreover, it might be noted that the reduction in pigment content of the moderately resistant species growing at the factory was expressed even more strongly than in the nonresistant ones. Despite considerable change in pigment concentrations of woody plants under test conditions, their relative distribution in the total sum remains close to that of the control. A similar picture is observed in calculations on the wet weight (Table 8). Chlorophyll a is more severely decomposed in woody plants under factory conditions and chlorophyll b, less. As a consequence of this, the chlorophyll a/chlorophyll b ratio of moderately resistant and nonresistant species decreases from that of the garden, and it even increases in resistant species. While the chlorophyll a/chlorophyll b ratio in the botanical garden is less in the resistant species of plants, it is less in the moderately resistant and nonresistant ones under factory conditions.

Statistical calculations (Table 10) have shown that there is a significant direct connection between damage to woody plants (wet weight) of the botanical garden by sulfur dioxide and xanthophyll content. There is a nearly significant connection between content of lutein, neoxanthin, total of all pigments and plant damage. A similar relation was not found under factory conditions. With pigment content based on dry weight, a nearly significant direct connection was found, between plant damage and their neoxanthin content (factory and garden), chlorophyll a/chlorophyll b ratio (garden), as well as the chlorophyll a + b/yellow pigment ratio (garden). We attempted to verify the connection of gas resistance and

TABLE 10

CORRELATIVE CONNECTION BETWEEN PIGMENT CONTENT OF WOODY PLANTS AND THEIR DAMAGE BY SO_2

a Пигменты	b Корреляционная связь между повреждаемостью и содержанием пигмента								c Корреляционная связь между повреждаемостью и относительным содержанием пигментов на ХЗ по сравнению с садом		d Связь между повреждаемостью и %-ным распределением пигментов на ХЗ	
	e расчет на сырой вес				f расчет на сухой вес							
	g сад		h завод		g сад		h завод					
	r	$\frac{r}{m_r}$	r	$\frac{r}{m_r}$	r	$\frac{r}{m_r}$	r	$\frac{r}{m_r}$	r	$\frac{r}{m_r}$	r	$\frac{r}{m_r}$
i Хлорофилл *а*	0,03	0,16<3	0,06	0,26<3	−0,03	0,16<3	−0,16	0,73<3	—	—	−0,13	2,5<3
j Хлорофилл *б*	0,09	0,5<3	0,04	0,17<3	−0,23	1,43<3	0,11	0,5<3	—	—	0,37	2<3
k Сумма хлорофиллов	0,06	0,33<3	0,01	0,04<3	−0,15	0,83<3	0,11	0,5<3	−0,3	1,4<3	−0,45	2,5<3
l Лютеин	0,25	1,47<3	0,01	0,04<3	0,22	1,29<3	0,21	1,0<3	0,37	2<3	0,13	0,59<3
m Виолаксантин	0,21	1,23<3	0,22	1,0<3	0,22	1,29<3	−0,05	0,24<3	0,87	17>3	0,61	4,3>3
n Неоксантин	0,36	2,24<3	0,15	0,68<3	0,31	1,93<3	0,16	2,55<3	0,16	0,7<3	0,15	0,7<3
o Сумма ксантофиллов	0,43	3,07>3	0,01	0,03<3	0,22	1,29<3	0,18	0,81<3	−0,2	1<3		
p Сумма всех пигментов	0,25	1,47<3	0,06	0,39<3	−0,17	0,9<3	0,23	1,09<3	—	—	0,41	2,3<3
q Отношение $\frac{\text{хл. } a}{\text{хл. } б}$	0,09	0,54<3	0,01	0,01<3	0,30	2,25<3	−0,23	1,15<3	—	—	—	—
r Отношение $\frac{\text{виолаксан.}}{\text{лютеин}}$	0,22	0,11<3	0,2	0,91<3	0,18	1,0<3	0,28	1,4<3.	—	—	—	—
s Отношение $\frac{\text{хл. } a+б}{\text{ксантофил.}}$	0,11	0,61<3	0,06	0,2<3	0,31	1,00<3	0,02	0,09<3	—	—	—	—
t Процентное содержание хлорофилла от суммы пигментов	−0,11	0,61<3	0,01	0,06<3	−0,07	0,39<3	0,07	0,31<3	—	—	—	—

Key:
a Pigment
b Correlative Connection between Damage and Pigment Content
c Correlative Connection between Damage and Relative Pigment Content at Chemical Plant, Compared with Garden
d Connection between Damage and Percentage Pigment Distribution at Chemical Plant
e Based on Wet Weight
f " " Dry "
g Garden
h Factory
i Chlorophyll a
j " b
k Total Chlorophylls
l Lutein
m Violaxanthin
n Neoxanthin
o Total Xanthophylls
p " of all Pigments
q Chlorophyll a/Chlorophyll b Ratio
r Violaxanthin/Lutein Ratio
s Chlorophyll a+b/Xanthophyll Ratio
t Chlorophyll Content as % of Total Pigments

change in pigment content of the leaves under factory conditions. In this case, a nearly functional connection was found, between plant damage and destruction of violaxanthin ($r = 0.87$; $r/m_r = 17 > 3$), and a nearly significant connection with destruction of lutein. Since the distribution of individual pigments in the sum total is not connected with gas resistance under botanical garden conditions (Table 6) and specific changes in pigment composition are observed under chemical plant conditions, their connection with plant damage was tested. It is evident from Table 10 that there is a statistically significant direct connection of plant damage and the presence of violaxanthin, and a nearly significant one, with the presence of chlorophyll a and b, total chlorophylls and total of all pigments.

The nature of the connection between plant damage and the relative distribution of pigments attracts attention. Under factory conditions, the degree of damage is inversely related to chlorophyll a and total chlorophyll content and directly related to chlorophyll b and the total of all pigments. The nature of the connections established can be understood, if it is considered that the pigment composition of the leaves of woody plants was changed, under the influence of acid gases.

It was noted earlier that the degree of destruction of pigments in individual species at the factory depends on gas resistance: an increase in pigment content was observed frequently in resistant species and a decrease in moderately resistant and nonresistant species. Therefore, the higher the percentage of chlorophyll a, total chlorophyll a and b and all pigments, the less the damage to the species by the gas. On the other hand, species with low chlorophyll b and violaxanthin content have high gas resistance under factory conditions.

TABLE 11

EFFECT OF SULFUR DIOXIDE ON PIGMENT CONTENT OF PLANT LEAVES UNDER EXPERIMENTAL CONDITIONS (SO_2 CONCENTRATION 0.04% - 1 HOUR)

a Виды растений	b Варианты опыта	c Хлорофилл *a*	d Хлорофилл *б*	e Хлорофилл *a* + *б*	f Лютеин	g Виолаксантин	h Неоксантин	i Сумма желт. пигмент.	j Сумма всех пигмен.	k Отношения: m хл. *a* / хл. *б*	k Отношения: n хл. *a* + *б* / ж. п.	l Процентное содержание пигмента в сумме всех пигментов: хлорофилл *a* c	хлорофилл *б* d	хлорофилл *a* + *б* e	лютеин f	виолаксантин g	неоксантин h	сумма желт. пигмент. i
o Расчет пигментов							на 1 *г* сырого веса											
p Клен ясенелистный	r Контр. 1	0,64	0,50	1,14	0,22	0,10	0,06	0,38	1,52	1,28	3,0	42,1	32,9	75,0	14,5	6,7	3,9	25,0
Клен ясенелистный	s Опыт 1	0,55	0,37	0,92	0,14	0,05	0,02	0,21	1,13	1,48	4,38	48,7	32,7	81,4	12,4	4,4	1,8	18,6
q Барбарис обыкновенный	r Контр. 2	0,24	0,17	0,41	0,09	0,06	0,03	0,18	0,59	1,41	2,28	40,7	28,8	69,5	15,2	10,2	5,1	30,5
Барбарис обыкновенный	s Опыт 2	0,30	0,16	0,46	0,07	0,02	0,02	0,11	0,57	1,87	4,18	52,6	28,1	80,7	12,3	3,5	3,5	19,3
t Расчет пигментов							на 1 *г* сухого веса											
p Клен ясенелистный	r Контр. 1	2,31	1,81	4,12	0,81	0,39	0,23	1,43	5,55	1,28	2,9	41,6	32,6	74,2	14,6	7,0	4,1	25,8
Клен ясенелистный	s Опыт 1	0,86	0,58	1,44	0,21	0,08	0,04	0,33	1,77	1,48	4,36	48,6	32,8	81,4	11,8	4,5	2,3	18,6
q Барбарис обыкновенный	r Контр. 2	0,39	0,27	0,66	0,15	0,10	0,04	0,29	0,95	1,44	2,27	41,0	28,4	69,4	15,8	10,5	4,2	30,5
Барбарис обыкновенный	s Опыт 2	0,89	0,47	1,36	0,20	0,07	0,05	0,32	1,68	1,89	4,25	52,98	27,98	80,96	11,9	4,16	2,98	19,04

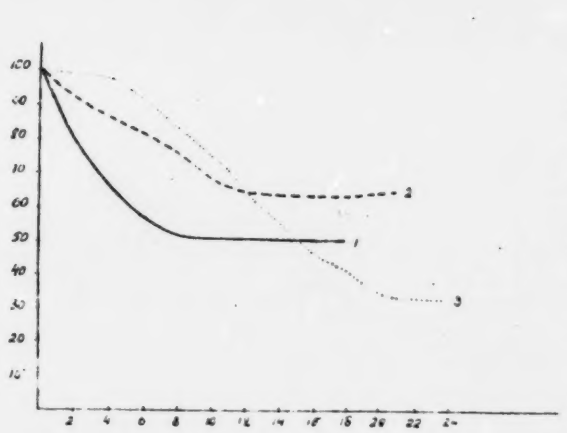
Key:
- a Plant Species
- b Test Version
- c Chlorophyll a
- d " b
- e " a+b
- f Lutein
- g Violaxanthin
- h Neoxanthin
- i Total Yellow Pigments
- j " All "
- k Ratio
- l Percentage Content of Pigment in Total of All Pigments
- m Chlorophyll a/Chlorophyll b
- n " a+b/Yellow Pigments
- o Calculated Pigments per g of Wet Weight
- p Box Elder
- q Common Barberry
- r Control
- s Test
- t Calculated Pigments per g Dry Weight

The experimental effect of 0.04% SO_2 for a period of 1 hour on elder and barberry leaves (Table 11) showed that a reduction in content of all pigments is observed in the elder (resistant species), regardless of the method of calculation, and even an increase in chlorophyll a and b and lutein concentration in barberry (nonresistant). The pigment distribution in the elder under control and test conditions was similar, but the proportion of chlorophyll a increased and the relative content of yellow pigments decreased in the barberry.

The rate of destruction of pigments of lawn grasses and woody plants in vitro by sulfur dioxide was determined (Figs. 4-7). In the heading phase, chlorophyll a and neoxanthin are quickly destroyed in fescue and chlorophyll a and violaxanthin in timothy, in which carotene and chlorophyll b are destroyed relatively more slowly. In the flowering phase, neoxanthin and lutein are quickly destroyed in fescue and chlorophyll a and neoxanthin in timothy. In the aftergrass phase of both species, carotene and chlorophyll a are destroyed quickly. Chlorophyll a is destroyed more quickly and all remaining pigments, somewhat more slowly, in woody plants.

Discussion

Significant differences in the chlorophyll a and b content and in the chlorophyll a/chlorophyll b and chlorophyll a + b/yellow pigment ratios have not been found in lawn grasses, with the exception of the tillering phase. Moreover, some differences in carotene and xanthophyll content, their total, as well as differences in the total xanthophyll to carotene ratio, have been observed by growth phases. It has been established that the method of calculation of the pigment content of



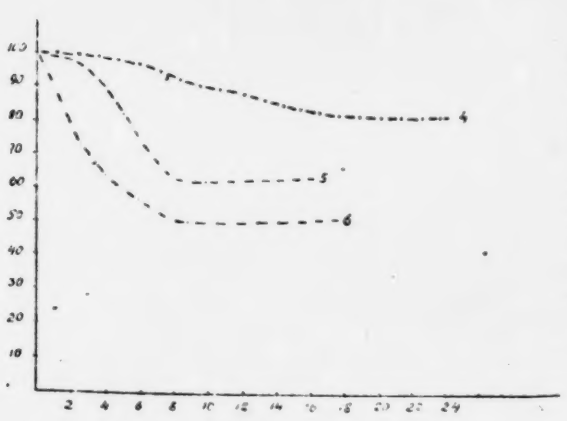
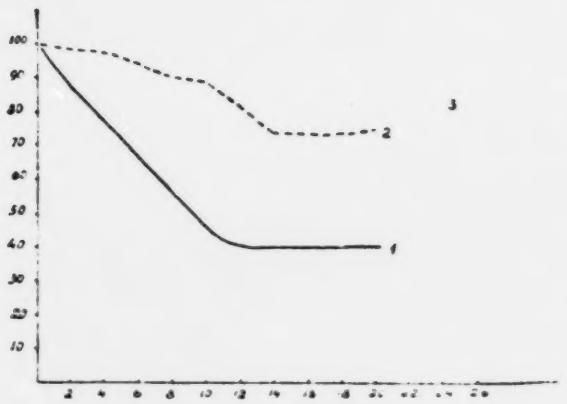


Fig. 4. Destruction of timothy pigments in heading phase by SO_2 in vitro (on ordinate, pigment content in %; on abscissa, amount of SO_2 passed through in ml): 1. chlorophyll a; 2. chlorophyll b; 3. carotene; 4. neoxanthin; 5. lutein; 6. violaxanthin.



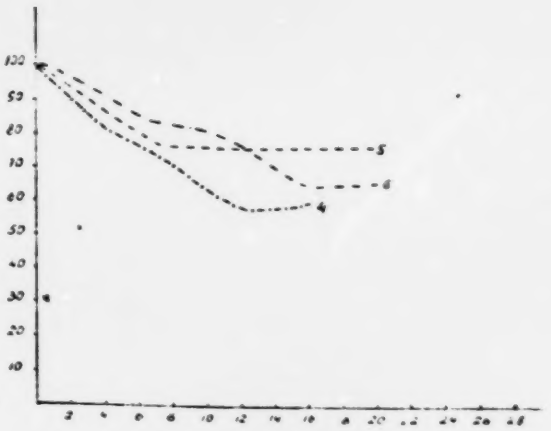


Fig. 5. Destruction of timothy pigments in flowering phase by SO_2 in vitro (on ordinate, pigment content in %; on abscissa, amount of SO_2 passed through in ml): 1. chlorophyll a; 2. chlorophyll b; 3. carotene; 4. neoxanthin; 5. lutein; 6. violaxanthin.

woody plants is of definite importance for gas resistance. If the pigment concentration is based on dry weight of a leaf, all species have close and very similar pigment contents. If the calculation is based on 1 g of wet weight, species which differ in gas resistance will have significant differences in pigment content. Thus, resistant species, under botanical garden conditions, contain less chlorophyll a and b, lutein, neoxanthin

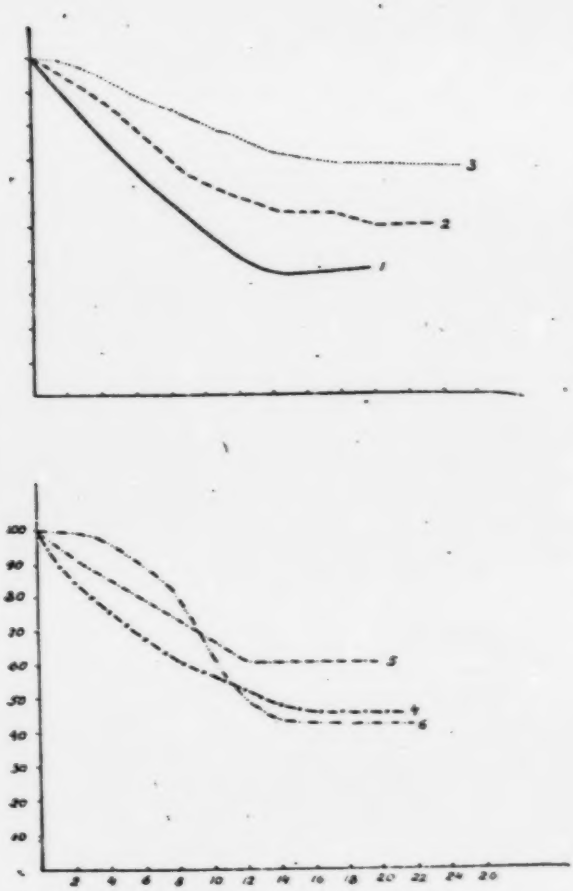


Fig. 6. Destruction of fescue pigments in heading phase by SO_2 in vitro (on ordinate, pigment content in %; on abscissa, amount of SO_2 passed through in ml): 1. chlorophyll a; 2. chlorophyll b; 3. carotene; 4. neoxanthin; 5. lutein; 6. violaxanthin.

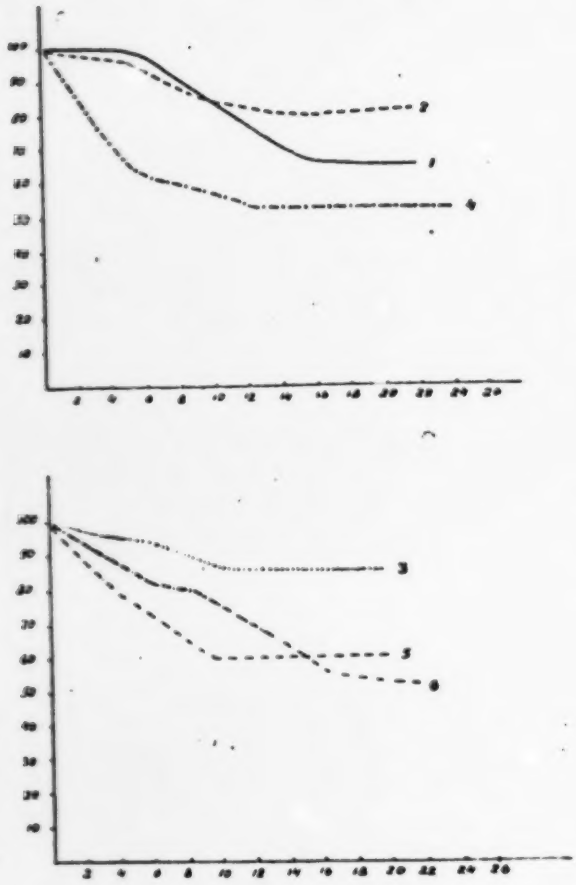


Fig. 7. Destruction of fescue pigments in flowering phase by SO_2 in vitro (on ordinate, pigment content in %; on abscissa, amount of SO_2 passed through in ml): 1. chlorophyll a; 2. chlorophyll b; 3. carotene; 4. neoxanthin; 5. lutein; 6. violaxanthin.

and the total of all pigments in 1 g of wet weight of leaves than non-resistant species. Calculation of the correlative connection between the content of individual pigments and gas resistance of plants (Table 10) has demonstrated the presence of a nearly significant dependence of damage on content of lutein, neoxanthin, total xanthophylls and all pigment.

The different results (depending on method of calculation) are connected with differing water content in the leaves of woody plants. We established earlier (Nikolayevskiy, 1965) an inverse correlative connection of damage with total water content in leaves of woody plants. Resistant species have more water in the leaves than nonresistant ones; therefore, in a calculation based on wet weight, they contain less pigments than non-resistant ones. On the other hand, the phenomenon found is completely regular, since the pigments perform their important photochemical functions in the chloroplasts of the plant, with a definite water content of the tissues and the cells, characteristic of each species. In a calculation based on dry weight, the differences in water content and the biochemical functions of the plant pigments are leveled out.

The absence of clear differences in pigment content in lawn grasses, in connection with gas resistance, can be linked to the biological differences between these groups of plants. Grassy plants are more mesophytic than woody ones, and the ecological differences between the two species of lawn grasses are not very significant.

The amount of pigments in the leaves is of great importance for gas resistance of plants, for two reasons. To a certain extent (Lyubimenko, 1963a, b) it characterizes the potential photosynthetic capacity of the plant. Consequently, not only direct determination of photosynthesis, but indirect (pigment content), confirms the dependence of gas resistance of plants on the photosynthesis rate (Nikolayevskiy, 1963, 1967; see article of Nikolayevskiy et al. in this collection). On the other hand, the pigment concentration is a means of regulating the amount of light energy absorbed (Lyubimenko, 1963b), which, according to the hypothesis

of K. Noack (Noack, 1925) and N. P. Krasinskiy (Krasinskiy, 1950), in the case of the action of sulfur dioxide, is directed by the pigments to the photodynamic oxidative processes. Consequently, a direct connection between pigment content and damage to woody plants can be an indirect confirmation of the hypothesis of K. Noack and N. P. Krasinskiy.

The role of individual pigments in photosynthesis has not been elucidated up to now. D. I. Sapozhnikov (1962, 1965) considers that carotene and the violaxanthin-lutein system, together with chlorophyll a and b, participate in photosynthesis. Some authors (Bishop, 1962; Allen, 1962; Sayger, 1962) ascribe a protective function to carotene, the xanthophylls and even chlorophyll b: These pigments protect chlorophyll a from bleaching in bright sunlight. It is likely that they are capable of performing both of these functions to differing degrees, depending on the solar radiation intensity. As an indicator, permitting characterization of the protective role of yellow pigments in plants, we select the ratio of the total chlorophylls a and b to yellow pigments. In lawn grasses in the botanical garden, there is not a definite connection between these ratios and their gas resistance. An almost significant correlative connection of damage to the chlorophyll a + b/yellow pigment ratio ($r = 0.31$ and $r/m_r = 1.9 < 3$) has been found in woody plants.

Under factory conditions, a decrease in the ratio of total chlorophylls to yellow pigments (moderately resistant species), an increase in resistant ones and a slight increase in nonresistant, is observed in woody plants. This occurred as a consequence of the irregular decrease in content of individual pigments in different species (Tables 5-8).

N. Bishop (1962) observed, under experimental conditions in vitro, that carotene is more quickly destroyed by light. In our case, a parallel

and similar destruction of all pigments simultaneously is noted in non-resistant woody plants. Chlorophyll is destroyed more quickly than the yellow pigments in lawn grasses (Table 2). Thus, the latter do not play a special protective part in the gas resistance of the plant.

The chlorophyll a/chlorophyll b ratio may characterize the potential photochemical activity of the leaves. A high chlorophyll a content and a high chlorophyll a/chlorophyll b ratio probably are an indication of a high potential photosynthesis rate.

M. Allen (1962) showed experimentally that chlorophyll b can perform a protective function: The less chlorophyll b there is, the more sensitive is the alga Scenedesmus to bright light. According to existing ideas (Arnold, Mackley, 1962; Deysens, 1962), in an electron flux, pigments play the part of semiconductors in absorption of light. Therefore, the natural (garden) pigment ratio, in particular the chlorophyll a/chlorophyll b ratio, can be an indicator of photosynthetic activity of the plant and, under conditions of the constant action of gases (factory), an indicator of their gas resistance (Pelz, 1964). While, in the first year of growth, the value of the chlorophyll a/chlorophyll b ratio of timothy is somewhat higher than that of fescue (2.6-2.7), in the second year, it is higher in fescue. This can explain the change in gas resistance of the species with their age.

The chlorophyll a/chlorophyll b ratios of both species changed under the influence of acid gases (chemical plant). The chlorophyll a/chlorophyll b ratio was the lowest (garden) in resistant species (2.1) and the highest in nonresistant ones (2.5), and it was the opposite at the factory (resistant, 2.7; nonresistant, 2.1). A comparative isotope study of

photosynthesis in several woody plant species of differing gas resistance showed that (Nikolayevskiy, Firger, Belokrylova, 1970), under garden conditions, the photosynthesis rate is lower in resistant species and higher in nonresistant ones and the opposite at the factory. Consequently, there is a direct connection between the chlorophyll a/chlorophyll b ratio and the photosynthesis rate. On the other hand, a decrease in photosynthesis in the nonresistant species at the factory apparently is a consequence of a decrease in the chlorophyll a/chlorophyll b ratio. The extent of the effect of the gases on pigments and photosynthesis is a function of the gas resistance of the plant. The latter may be connected with differing rates of absorption of the toxic gases.

Our data on change in the chlorophyll a/chlorophyll b ratio and on destruction of pigments in solutions confirm the conclusion of E. Pelz (1964), that a reduction in the chlorophyll a/chlorophyll b ratio may characterize the gas resistance of a plant. Moreover, we observed such considerable reductions in values as they indicate, as an exception. In our opinion, the gas resistance characterizes more clearly, not a reduction in the chlorophyll a/chlorophyll b ratio, but a reduction in chlorophyll and total chlorophyll and yellow pigment concentrations. This is confirmed by calculation of the correlative connection of the relative distribution of pigments with plant damage. A dependence of the reduction in pigment concentrations in plants on degree of air pollution was noted by B. Marzhan (1962).

Experimental fumigation of lawn plants with sulfur dioxide disclosed differences in the effect of different concentrations of it, as well as a difference in the dependence of gas resistance of the species on time of

the aftereffects. Low concentrations of SO_2, as a result of slight acidification of the cell protoplasm, causes an increase in oxidative processes and considerable destruction of pigments in the first hours of the test. As a result of high concentrations of the gas, strong acidification of the protoplasm and inactivation of many enzymes takes place, which leads to stabilization of pigment contents in the first day.

An increase in pigment concentration on the second day after the action of low concentrations apparently can be connected, on the one hand, with an increase in pigment synthesis from the precursors and, on the other hand, with increase in their recoverability.

Both in the case of tests in vitro and in experiments using the gas on living plants, rapid destruction of chlorophyll a and carotene was observed. The low stability of chlorophyll a may be connected with its important photochemical role in photosynthesis: It not only absorbs light energy itself, but it receives it from other pigments. The high stability of chlorophyll b possibly depends on greater hydration and stronger bonds with water (Kutyurin, 1965). On the other hand, the fluctuating nature of change in pigment contents in plants, as functions of gas concentration and time of aftereffects, may be connected with the nature of the response reaction of the plant, as a system with feedback (Goodwin, 1966; Zhuravlev, 1967).

Conclusions

1. Significant differences in pigment content has not been found in lawn grasses which differ in gas resistance.

2. An inverse relation has been found in woody plants in a botanical garden (based on 1 g of wet weight) between the content of individual

pigments and gas resistance. Resistant species contain less pigment and have a lower chlorophyll a/chlorophyll b ratio.

3. The relative distribution of individual pigments is similar in all species, and it differs little in lawn and woody plants.

4. In acid gases on lawn grasses (chemical plant), a reduction in the content of individual pigments takes place (in the tillering, tubing and flowering periods of fescue and in the tillering period of timothy). The total pigment content decreased in the heading and tubing phases of fescue and heading and flowering of timothy. The intensity of the destructive effect of acid gases on the pigments was expressed more strongly in timothy and less in fescue.

5. The condition of the pigment systems of lawn plants depends on SO_2 concentration, time of results and species characteristics. Low concentrations cause destruction of many pigments on the first day and, on the second day, recovery of their content. High concentrations stabilize the pigment content on the first day and increase their decomposition on the second day.

6. The pigment content of woody plants grown under experimental conditions, differs significantly from that of plants grown under control conditions. The decrease in content of individual pigments and total pigments is more significant in nonresistant and moderately resistant species. Even an increase in it is sometimes observed in resistant plants. The chlorophyll a/chlorophyll b ratio increases in resistant species and decreases in nonresistant ones. However, this phenomenon may not be a universal and distinct indicator of gas resistance. The dependence of gas resistance on content of the majority of pigments and total pigments is

displayed more distinctly in woody plants.

7. A lower stability of chlorophyll a and carotene has been found in plants at the factory and in tests in vitro.

8. Statistical calculations have demonstrated a relation of gas resistance to total xanthophylls, as well as its relation to content of neoxanthin, lutein, total pigments and the relative content of violaxanthin (garden). Under the constant action of acid gases (chemical plant), a significant dependence has been found of gas resistance on content of violaxanthin, as well as on content of chlorophyll a, total chlorophylls and total of all pigments.

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